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**NOVEL USES OF A WIDE BEAM SADDLE FIELD ION SOURCE FOR
PRODUCING TARGETS USED IN NUCLEAR PHYSICS EXPERIMENTS AT
THE ARGONNE NATIONAL LABORATORY ATLAS FACILITY**

*John P. Greene and George E. Thomas
Physics Division, Argonne National Laboratory,
9700 South Cass Avenue, Argonne, IL 60439, USA*

*Stacey L. Schiel
University of Illinois, 190 Medical Sciences Bldg.
506 S. Matthews, Urbana, IL 61801, USA*

Abstract

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The wide beam ion sputter source has several unique characteristics which make it very useful for producing, reducing the thickness or cleaning the surface of targets manufactured from expensive separated isotope. A discussion of these techniques as well as the sputter source characteristics will be given. Sputter yields obtained utilizing this source are presented for a variety of materials common to nuclear target production.

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1. Introduction

The usefulness of sputtering as a method for the deposition of thin films used in nuclear target development is well established. The early use of small, inexpensive saddle field ion sources employed for sputtering has been described previously [1,2,3]. We present here a description of a new, compact wide beam saddle field sputter gun which can be utilized for the production of the targets needed for nuclear physics experiments. This wide beam sputter source is particularly suited to recent efforts involving target thinning and ion etching. Studies involving deposition rates obtained using this source with various materials will be given and compared with results obtained with a fine beam saddle field sources being carried out at other target laboratories [4]. Various uses of this system within the heavy-ion experimental program using ATLAS (Argonne Tandem Linear Accelerator System) at Argonne National Laboratory will be given.

2. Description of the Wide Beam Saddle Field Ion Source

The principle of operation of saddle field ion sputtering is well known. This source is designed to operate at levels up to 10 kV with beam currents as high as 250 μ A. A standard, constant voltage power supply Model B50 [5], is employed to provide power for the saddle field ion source. For the applications described we employed a Model B21bW [6] wide beam sputter source [7]. The compact size of the sputter gun and wide beam makes it a unique tool for several applications in the production of various targets to be used in heavy-ion experiments which were previously considered nearly impossible to make. A photograph of this sputter source is given in Figure 1. The type shown is the water-cooled version which allows for reduced heat radiated to the target and substrate under extended operation. Figure 2 gives the overall dimensions of the wide beam sputter gun.

The source is mounted in an aluminum holder positioned at the standard angle of 30 degrees with respect to the plane of the sputtering target. The angle was chosen on recommendations of previous work with saddle-field sources for the production of nuclear targets [1,3,4]. Although the yield will vary with incident angle of the sputtering ion, no attempt has been made to investigate maximum yield vs. angle of incidence for this source.

The source is adjustable in distance from the sputter material along aluminum rails which maintain this angle. The normal operation the source to evaporant distance is approximately 5 cm. The substrate, a backing foil mounted on a standard ATLAS target frame, is positioned only 2 cm or less above the sputter material. This short distance makes it possible to produce targets using small amounts of very expensive source material at much lower costs. Although the angular distribution of the sputtered material may vary considerably based on the energy of the sputtered beam as well as the material being sputtered, no effort was made to position the substrate so as to maximize collection of the sputtered material. For the determination of the deposition rate, a small, carefully weighed, small, thin glass disk is used as the substrate. A photograph of this sputtering arrangement is shown in Figure 3. A very attractive feature of this inexpensive set-up is that it is mounted completely on a vacuum feed-thru ring which is incorporated into the vacuum evaporator for use and removed when no longer needed. Thus the evaporator system has more flexibility for different uses.

3. Operational Characteristics

The source specifications given are for 5 kV operation with a plasma or source current of 2 mA. Under these conditions, the ion current obtained is about 100 μ A with a

gas pressure of 5×10^{-4} torr and 150 l/sec pumping speed. The operational characteristics, however, vary considerably and will be discussed in detail.

3.1 Beam Spot Size

The main motivation behind developing this source technology in the target laboratory is to build upon previous research with thinning foils by ion beam sputtering [8]. We have used the beam to thin or clean targets ~ 1.5 cm dia. and as thin as 130 ug/cm^2 . A schematical representation of this ion milling process is shown in Figure 4. The B21bW wide beam ion source produces a beam approximately 1 cm long and diverging at an angle of 15 degrees with respect to the beam axis. The source is mounted with the long axis of the aperture positioned vertically with respect to the sputter target. The beam spot obtained with this set-up shows sputtering from the target area of approximately $29 \text{ mm} \times 10 \text{ mm}$ in size. The operating parameters for the source using argon gas were 8 kV applied voltage and plasma current of 2 mA, giving a average beam current of $50 \text{ }\mu\text{A}$. The partial pressure of argon was approximately 1.8×10^{-5} torr.

An analysis of the ion beam spot size under these conditions, using thin gold and nickel films reveals a somewhat gaussian shaped intensity distribution with the highest intensity contained within the central 2mm of the beam. A scan of the beam profile is obtained using the film thickness of the sputtered foil determined by alpha particle energy loss measurements [9]. These scans are shown for foils of original thickness before sputtering of 3 mg/cm^2 for Au (Fig. 5) and Ni (Fig. 6), respectively.

3.2 Gas Handling

The sputter source is operated within a vacuum chamber employing a CTI Model CryoTorr-8 cryopump having a pumping speed of 1500 l/sec for nitrogen. Satisfactory operation of the source is obtained with a system pressure of $5\text{--}8 \times 10^{-5}$ torr. Due primarily to the increased pumping speed, the ultimate vacuum improves during initial operation of the source. This then requires periodic gas flow adjustments during the deposition which is reflected in the measured beam current.

The research described here concentrates on use of the noble gases. For the sputter yield studies, a partial pressure of $1\text{--}2 \times 10^{-5}$ torr of argon was used. Similar conditions were required for ion milling operations using krypton.

3.3 Beam Current Measurements

The symmetrical geometry of the saddle field source also produces a rear directed beam which is collected by the monitor plate. This aluminum monitor plate is connected to an ion current monitor with the beam current displayed on the power supply panel. Only a small part of the beam is collected on the monitor plate as it exits through the 1.5 mm diameter rear cathode. The ratio of the geometrical areas of the front to rear cathodes is approximately ten. In addition, only a fraction of the true beam intensity is reflected by the ion current monitor since the neutral content of the beam is not measured. For ion milling applications, the total beam intensity (ions+neutrals) must be taken into account as the momentum of the neutrals is similar to that of the ions and provide a substantial contribution to the sputtering yield as determined from etching rate measurements [10]. The neutral component of the beam is estimated to be approximately 20% of the total beam intensity [11].

Normal operating parameters for the wide beam source used an accelerating potential of 8 kV with a plasma current of 2 mA. Under these conditions, ion currents of about 40 μA were achieved. Figure 7 shows plots of ion current vs. accelerating voltage for several plasma currents obtained using this wide beam source.

4. Experimental Results and Applications

After establishing reliable operation of the source, a preliminary study was undertaken to determine deposition rates for a variety of materials common to nuclear target production. Applications involving ion milling were also investigated and a series of measurements performed.

4.1 Sputter Deposition Rates

Results are given here for a variety of materials from an investigation of deposition rates obtained using this wide beam ion source having argon as the sputtering gas. The operating parameters of the source for this study were 8 kV accelerating potential, a partial pressure of argon of $1-2 \times 10^{-5}$ torr, and a plasma current of 2 mA. The beam currents measured varied between 45 and 50 μA averaged over a 1 hour deposition time. Table I gives these sputtering rates and compares them with data previously published [12]. As the sputtering conditions vary considerably, these rates have been normalized to the rate obtained for copper. The results obtained are, in some instances, substantially greater for the wide beam source.

Since one of the purposes intended for this source was for ion milling, a series of deposition rate measurements were performed employing krypton in the ion source. Table II shows the results of these measurements for a variety of materials. The source was operated at 8 kV applied voltage and 2 mA plasma current with a partial pressure of krypton of $1-2 \times 10^{-5}$ torr. Beam currents obtained averaged closer to 40 μA as compared with 45-50 μA obtained using argon. The estimated erosion, or ion milling rate was based on the material consumed using the deposition rate measured, determined by careful weighing of the glass substrate, and the geometry of the set-up. For this purpose, the angular distribution of the sputtered material is assumed to be cosinusoidal. This assumption is not without merit as earlier studies have shown, and is based upon the calculations of Maier [4]. A more precise determination of the erosion could be obtained by accurately weighing the sputtered target foil before and after the milling process, thus measuring the amount of material ejected.

The statistical uncertainties in these measurements is difficult to establish since the main errors encountered are the precise duration time and the accuracies obtained from weighing microgram quantities. For the results presented here, several measurements were made. The deposition rates observed compare favorably with published data available from other laboratories using the fine beam saddle field source [13].

4.2 Ion Milling

Ion milling is a well known technique used for various materials. However, the wide beam sputter source is well suited for this use, in particular with targets to be used in heavy-ion experiments at ATLAS. These targets are usually no more than 1.5 cm dia. with thicknesses of 200-500 $\mu\text{g}/\text{cm}^2$. Often the scientist places the target in the experiment and finds it is too thick for optimum use. It can be immediately removed and thinned using the sputter source since the beam size is usually about the same diameter as the target. The target can then be put back into the experiment with little time loss. Targets of ^{106}Cd were thinned in this manner.

4.3 Target Cleaning

Often the target becomes coated with carbon or other contaminants deposited by the heavy-ion beam of the accelerator. Usually the target is then considered no longer useful since this surface contamination contributes undesirable background to the experiment. However, by using the wide beam sputter source, the surface contamination can be removed and the target cleaned for use again. The target must be rotated occasionally while being cleaned in order to obtain uniformity of the target surface. As for example a ^{160}Gd target was cleaned in this manner.

Also, the wide beam source has been used to remove oxide layers from targets which may be once oxidized during handling as well as from beam exposure. An example is the lead stopper foils ($\sim 30 \text{ mg/cm}^2$) used in experiments at GAMMASPHERE in which an oxide layer was unacceptable. The oxide layer was removed with approximately 2 mg/cm^2 of thinning and the targets were available for continued use.

5. Conclusions

The small wide beam sputter source is particularly suited for use with the Argonne National Laboratory ATLAS accelerator. Its beam size is ideal for reducing the thickness of targets while an experiment is in progress, cleaning of special targets and removing oxide layers from other targets. Thus, both expensive running time and the targets themselves are preserved. Many uses for which it is especially adapted will be found in the future.

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Tables

- Table I - Table of Ion Beam Sputtering Deposition Rates using Argon.
- Table II - Deposition Rates and Estimated Erosion Based on Consumption Rates for Various Materials using Krypton.

Figure Captions

- Figure 1. Photograph showing the B21bW Wide Beam Saddle Field Ion Source.
- Figure 2. Drawing of the B21bW Wide Beam Saddle Field Ion Source.
- Figure 3. Schematic Representation of the Ion Milling Process.
- Figure 4. Photograph showing the sputtering set-up.
- Figure 5. Beam profile scan from film thickness measurements of a sputtered 3 mg/cm^2 Au foil as determined by alpha particle energy loss measurements.
- Figure 6. Beam profile scan from film thickness measurements of a sputtered 3 mg/cm^2 Ni foil as determined by alpha particle energy loss measurements.
- Figure 7. Plot of Ion Current vs. Accelerating Voltage for a variety of Plasma Currents.

Table I
(for Argon)

Element	Deposition ^{a)} Rate (Å/minutes)	Our Results (Å/minutes)
Copper	100	100
Aluminum	49	54
Silicon	35	--
Titanium	21	50
Chromium	26	86
Iron	37	43
Nickel	59	109
Germanium	51	--
Molybdenum	39	47
Silver	170	175
Tungsten	30	36
Platinum	138	73

^{a)}from Ref. [10].

Table II
(for Krypton)

Target Foil	Deposition Rate ($\mu\text{g}/\text{cm}^2/\text{hr}$)	Estimated Erosion Based on Consumption Rate (mg/hr)
C	1.4	.02
Mg	29.5	.37
^{27}Al	25.3	.32
Ti	28.1	.35
Cr	47.7	.60
Fe	71.5	.90
Ni	71.5	.90
Cu	109.4	1.37
Zn	222	2.79
Mo	58.9	.74
Ag	230	2.89
Sn	162.7	2.04
W	110	1.38
Pt	192	2.41
^{197}Au	236	2.97
Pb	311	3.91
^{209}Bi	321	4.03

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Au Foil Beam Profile

Fig. 5

Ni Foil Beam Profile

Fig. 6

Current vs. Voltage

Fig. 7